Reduction of Perfluorocarbon (PFC) Emissions at DUBAL Potlines
Introduction to Dubal

Vision

To be one of the best companies in the global aluminium industry in production, markets, people and results by 2020.

- One of the world’s largest producers of primary aluminium smelters located at Jebel Ali (~1 million tpa) employing > 4000 people

Facilities:

- Potlines with D18, D20, CD20 and DX electrolysis cell technologies
- Casthouses (>1.2 million tpa), 2,350 MW power station (30°C), 30 million gallon/day desalination plant, Port facilities etc.,

Markets

- Asia: 39%
- MENA: 26%
- Europe: 15%
- Americas: 20%

Products

- Billet: 61%
- Foundry: 6%
- Super-high and high purity: 3%
- Others: 30%
Define Phase
Aluminium Electrolysis – Main Process

- Alumina Hopper
- Anode Beam (Ring Bus)
- Anode Rod
- Carbon Cathode
- Collector Bar
- Melted Aluminium
- Melted Cryolite (Electrolyte)

DC current enters from previous cell
DC current exits to next cell
Aluminium Electrolysis – Main Process

[$2\text{Al}_2\text{O}_3 + 3\text{C} = 4\text{Al} + 3\text{CO}_2$]

PFC formation – undesirable process output – PFC’s contribute to greenhouse effect

$\text{Al}_2\text{O}_3 + 2\text{AlF}_3 + 3\text{C} = 3\text{COF}_2(\text{g}) + 4\text{Al}$

$2\text{COF}_2 + \text{C} = 2\text{CO}(\text{g}) + \text{CF}_4(\text{g})$
On a global basis, PFC’s contribute about one third of all direct greenhouse gas emissions from primary aluminium production. Reduction of PFC’s is important as a long term strategy and in line with Dubal’s vision. Hence this project on PFC reduction.

From http://www.ucsusa.org
Achieve better results through operational and service excellence

**Project selection process**

**DUBAL BALANCED SCORECARD**

- **Executive Management** Responsible for Selecting the Project
- **P9** – Achieve World Class EHS Performance
- **EHS Strategy Map**
- **P3** – Enhance Environmental Performance

**Smelter Ops Strategy Map**

- **SP9** – Strive to achieve world class EHS standards

**Define**
Problem statement

PFC emissions in 2007 for Point fed prebaked (PFPB) cells were much higher than top 10 Aluminium Smelters in this category, and this was not inline with corporate vision.

Project goal:

40% Reduction in Plant PFC emissions from 2007 base line of 237 kg CO$_2$/t Al by end of 2012 and improve standing in the benchmarking.

2007 PFC Emissions Benchmarking Data Vs. 2007 performance

![Graphs showing PFC emission rank for other PFPB smelters and CWPB smelters in 2007.](image)

**Project Scope**

- Aluminium Smelting (Potlines)

**Out of Scope**

- Reduction Materials, Power and Casting Operations
Area of opportunity is the electrolysis process
Second level process map

Alumina Storage Silo

Conveying System

Alumina Distribution system

Alumina

Raw material flow to the Cell

AlF₃ feed Logic

Alumina feed Logic

Anode setting Logic

DC Current & Volts

Resistance control & Current / Voltage

Signal Processing Logic

Tapping Logic

New pot start-up Logic

Highlighted areas were identified as opportunities to reduce PFC emissions

Pneumatic Interface Cubicle

Hardw are Activation

Electrolysis Cell

- Work routines
- Mass and Energy balance
- Crust breaker feeder hardware Condition

Cell Control Unit or PLC

Monitoring / Control Process Parameters

Host Machine Database Server

Oracle Database

Reduction Plant Monitoring System (RPMS)

Communication Server

Potline Programs

Shared Memory

Binary Flies

Communication Module

Control Application

Second level process map for identifying the opportunities - refer highlighted areas
Aluminium Smelting

- Suppliers
  - Power plant
  - Reduction Material
  - Dock
  - Laboratory
  - Process Control
  - Reduction Services
  - Fume Treatment Plant
  - Maintenance
  - Engineering
  - Finance
  - Supply
  - R&D
  - IT
  - EHS Department
  - Jerry Marks & Associate
  - Welbank consulting

- Inputs
  - Energy
  - Aluminium Fluoride
  - Alumina
  - Analysis Results
  - Knowledge & skills
  - Operation Support
  - Secondary Alumina & Emissions Control
  - Maintenance Schedule
  - Capital Budget
  - Operating Budget
  - Equipment’s & Spares
  - Technology
  - Computer Programs
  - EHS Standards
  - PFC Measurements
  - Process Knowledge

- Process
  - Aluminium Smelting
  - Start: Receive Alumina at Dock
  - Feed & dissolve alumina in cryolite melt kept @ ~ 960degC
  - Pass ~ 4.5 VDC & 200-400 kA to electrolysis cell
  - Tap Liquid metal from The cell

- Outputs
  - Liquid Aluminium
  - PFC & Other Emissions
  - Effluent
  - Solid Waste

- Customers
  - Internal
    - Cast house
    - EHS Department
  - External
    - Customers
      - IAI (International Aluminium Institute)
      - GAC (Gulf Aluminum Council)
      - DCCE (Dubai carbon Center of Excellence)

Stakeholder group identification

Define
# Team charter

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>Data Collection</th>
<th>Data Analysis</th>
<th>Implementation</th>
<th>Control</th>
<th>Specialist</th>
<th>Project Review</th>
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<tr>
<td>Dr. Ali Al Zarouni</td>
<td>Project Sponsor</td>
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<td>Dr. Maryam Al-Jallaf</td>
<td>Project Leader</td>
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<td>A Kumar / Dr. D. Whitfield</td>
<td>Plan and monitor trials</td>
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<td>Provide summaries and conclusion</td>
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<td>Support direct PFC measurements</td>
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<td>Greg / Jose / Ali Jassim / Rawa</td>
<td>Process calculations</td>
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<td>Executing improvement trials &amp; data analysis Support direct PFC measurements</td>
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<td>Dr. Venkat</td>
<td>Literature survey &amp; Interpretations</td>
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<td>Dinesh Kothari</td>
<td>Control systems development (programming)</td>
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<td>Sergey / Konstantin</td>
<td>Control systems development (signal analysis and logic)</td>
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<td>Alex</td>
<td>Electrolysis cell modelling and development</td>
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<td>Kamel / Devadiga / Vallabhan</td>
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<tr>
<td>Abdulla Zarouni</td>
<td>DX/ DX+ Technology development</td>
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# Team charter

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<tr>
<td>N. Rana</td>
<td>Statistical analysis and interpretation of trial results</td>
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<td>Sara Khalfan</td>
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<td>Ghedyer Hamad</td>
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<td>Najm Alawadhi</td>
<td>Provide data about alumina shipments</td>
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<td>M. Tawfik</td>
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<td>S. Gowda</td>
<td>Maintain and refurbish alumina feeding systems and superstructures of electrolysis cell</td>
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<td>Define Phase</td>
<td>Possible Opportunities to Reduce PFC emissions</td>
<td>Q1 - Q2/2009</td>
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<td>Measure Phase</td>
<td>Measurement system validation and project base line</td>
<td>Q3/2009 – Q2/2010</td>
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<td>Analysis Phase</td>
<td>Identification of possible causes and filtration of root causes</td>
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<td>Control Phase</td>
<td>Control actions to sustain improvements</td>
<td>Q2/2011 – Q4/2012</td>
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</table>
Quick win

Waiting period in control system before starting to quench anode effect was reduced to improve the response time of control system and reduce AE duration.
Measure phase
# Measurement plan

For each electrolysis cell the IT systems continuously record and store parameters in database.
Measurement system analysis

- Cell control unit measures cell voltage and also has a built-in clock.
- Measurement of PFC depends on these two parameters.
- Voltage measurement is calibrated at the workshop using voltage generators that are accredited to international standards – measurement capability is extremely good.
- Procedure is part of the ISO 9001 system.
- The clock time is continuously synchronized to GPS.
Measurement system analysis

- **Slope:**
- % Linearity
- **Result – Gage is non-linear and un-biased**
Project baseline - PFC emission

Avg. PFC (plant) = 222 Kg CO₂ eq/t Al
Std. Dev. = 30.9
PPM = 405469
Sigma level = 0.24

Project base line shows that actual avg. PFC is lower than the target but the variation is large.
Analyse phase
Project team identified possible causes with the help of Ishikawa diagram.
Possible causes

Software
- Inadequate sophistication in Alumina feed logic
- Over Smoothening of cell resistance
- Effectiveness of Anode effect termination logic
- Availability of process data in user friendly format

Equipment and Machinery
- Erosion of crust Breaker
- Alumina delivery system

Process & People
- Amperage creep and increased current density
- Variation in Compressed Air Pressure and flow
- Lack of awareness about implication of anode effect
- Fluctuation in Alumina Quality
- Deficiency in pot start up process
- Human error due to fatigue/ lack of awareness

12 possible causes shortlisted.
Data generation and analysis

**Data Generated**
1. Process Knowledge
2. Process Data
3. Process Parameter Data & PFC Emission Data

**Analysis Method**
1. Why-Why analysis
2. Hypothesis Testing
3. Trend Charts

**Examples**
- Boxplot of L9 AEF Before weekly, L9 AEF After weekly
- PFC Emissions Trend, kgCO₂eq/t Al
Possible Causes

1. Inadequate sophistication in Alumina feed logic
2. Over Smoothening of cell resistance
3. Effectiveness of Anode effect termination logic
4. Erosion of crust Breaker
5. Alumina delivery system
6. Amperage creep/ increased current density
7. Variation in Compressed Air Pressure and flow
8. Lack of awareness about implication of anode effect
9. Fluctuation in Alumina Quality
10. Deficiency in pot start up process
11. Human error due to fatigue/ lack of awareness
12. No anode effect prediction logic available

Analysis Method

Why Why Analysis

Hypothesis Testing

Trend Charts

Final Root Causes

1. Inadequate sophistication in Alumina feed logic
2. Over Smoothening of cell resistance
3. Effectiveness of Anode effect termination logic
4. Variation in Compressed Air Pressure and flow
5. Fluctuation in Alumina Quality
6. Deficiency in pot start up process

Possible causes screened and 6 main causes identified.
Validation of root causes

Final Root Causes

1. Inadequate sophistication in Alumina feed logic
2. Over Smoothening of cell resistance
3. Effectiveness of Anode effect termination logic
4. Variation in Compressed Air Pressure and flow
5. Fluctuation in Alumina Quality
6. Deficiency in pot start up process

Validation Method

✓ Hypothesis Testing
✓ Mann Whitney Test
✓ Two Sample T Test
✓ Trend Charts

Examples
Improve phase
Parameter requests are approved formally by stakeholders
Identification of possible solutions

**Tools/ Methods for possible improvements**

- Brainstorming
- Literature Survey
- Consultation with technical experts
- Mass energy Balance calculations
## Solution prioritization

<table>
<thead>
<tr>
<th>Root causes</th>
<th>Possible Solutions</th>
<th>Cost</th>
<th>Relevance</th>
<th>Time</th>
<th>Rank</th>
</tr>
</thead>
</table>
| **Alumina feed logic** | 1. Examine the algorithm and implement changes as needed  
2. Buy sophisticated logic from external vendor  
3. Increase manpower or ask employees to work longer hours | 5    | 5         | 3    | 13   |
| **Smoothening resistance** | 1. Develop alternative smoothening equations & near AE logic  
2. Dampen the trigger level for alumina feeding  
3. Buy sophisticated logic from external vendor  
4. Increase manpower or ask employees to work longer hours | 5    | 5         | 3    | 13   |
| **AE termination** | 1. Develop improved logic  
2. Buy sophisticated logic from external vendor  
3. Increase manpower or ask employees to work longer hours | 5    | 5         | 3    | 13   |
| **Compressed air** | 1. Increase compressed air pressure and availability  
2. Install portable compressor at specific locations where needed  
3. Identify sources of air leaks / wastages and eliminate | 3    | 3         | 4    | 10   |
| **Alumina quality** | 1. Managing receipt and storage, handling of alumina from different sources in methodological manner and continuously update stakeholders  
2. Single source alumina from one refinery  
3. Tighten specification for purchase  
4. Offer higher premium to suppliers  
5. Make our own alumina | 5    | 5         | 4    | 14   |
| **Cell start up** | 1. Process change  
2. Buy sophisticated logic from external vendor | 4    | 4         | 4    | 12   |

Possible solutions identified and 9 final solutions selected from these.
Validation of final solutions

Final Solutions

1. Examine the algorithm and implement changes as needed
2. Develop alternative smoothening equations & near AE logic
3. Dampen the trigger level for alumina feeding
4. Develop improved logic
5. Improve compressed air availability
6. Install portable compressor at specific locations where needed
7. Identify sources of air leaks / wastages and eliminate
8. Managing receipt and storage, handling of alumina from different sources in methodological manner and continuously update stakeholders
9. Cell Start-up process enhancement

Tools/ Methods for final improvements validation

- Pilot test
- Compare test vs. controls
- Hypothesis test
- Trend analysis
- Feedback from stakeholders

Examples

Some examples are illustrated in following slides
Validation of final solutions

Sophisticated Feed Logic Based on Mass energy balance

Final solutions validated before full scale implementation
## Action plan for implementing the solutions

<table>
<thead>
<tr>
<th>Schedule for implementing the final solutions</th>
<th>complete by</th>
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<tbody>
<tr>
<td>1: Examine alumina feed algorithm and implement changes</td>
<td>Q4 2011</td>
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<tr>
<td>2: Alternate smoothening equation and near AE logic</td>
<td>Q2 2012</td>
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<td>3. Dampen the trigger level for alumina feeding</td>
<td>Q2 2011</td>
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<td>4. Develop improved logic for AE termination</td>
<td>Q3 2011</td>
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<tr>
<td>5. Improve compressed air availability</td>
<td>Q2 2012</td>
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<tr>
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<td>Q3 2012</td>
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<tr>
<td>7. Identify sources of air leaks / wastages and eliminate</td>
<td>Q2 2012</td>
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<tr>
<td>8. Managing receipt and storage, handling of alumina from different sources in methodological manner and continuously update stakeholders</td>
<td>Q2 2011</td>
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<tr>
<td>9. Cell Start-up process enhancement</td>
<td>Q4 2011</td>
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</table>
Results

Process performance

PFC emissions reduced by 50% Vs. target 40% (2007 base)
CpK improved

Avg. PFC = 222.6 t CO₂ eq/ t Al
Std. Dev. = 30.9
PPM = 405469
Sigma level = 0.24

Avg. PFC = 119.5 Kg CO₂ eq/ t Al
Std. Dev. = 18.7
PPM = 0
Sigma level = 5.91

Avg. PFC = 222.6 t CO₂ eq/ t Al
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Avg. PFC = 119.5 Kg CO₂ eq/ t Al
Std. Dev. = 18.7
PPM = 0
Sigma level = 5.91
Results

PFC emissions reduce by 50% Vs. target 40% (2007 base)

Additional Benefits

1. Less Energy consumption
2. Small Improvement in Productivity
3. Small improvement in process efficiency

PFC emissions reduced from 237 to 121 kg CO2/ tAl
Results

Improved standing in the industry for both Point Fed Prebake (PFPB) and Center Work Prebaked (CWPB) technologies.
Control phase
Sustaining the improvement

- Monitoring of Anode effect performance
- New PFC reports added in iRPMS, iPOTS and analytics
- Performance management system linked with project objectives
- PFC emission related publications in conferences / journals
- Continue benchmarking exercise with IAI
- Part of QMS and EMS management system
## Stakeholders involvement in sustaining improvement

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>Area</th>
<th>How</th>
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<tr>
<td><strong>Internal</strong></td>
<td></td>
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<tr>
<td>Operation Managers</td>
<td>Potlines</td>
<td>Monthly Meetings / Informed through email, follow up</td>
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<tr>
<td>Operations Staff</td>
<td>Potlines</td>
<td>Monthly meetings / operational feedback on trials</td>
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<tr>
<td>Process Control Manager</td>
<td>Potlines and Cell relining</td>
<td>Weekly meetings/ Monthly reports, follow up</td>
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<tr>
<td>Process Control Engineers</td>
<td>Potlines and Cell relining</td>
<td>Follow-up / Sharing best practices meeting, follow up, Technical feedback on trials</td>
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<tr>
<td>Manager/Engineers</td>
<td>Performance Improvement</td>
<td>Planning/ Weekly meetings/ Sharing best practices meeting, follow up, Technical feedback</td>
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<td>Informed through email</td>
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<td>Development Manager/Engineers</td>
<td>Cell Technology Development</td>
<td>Weekly meeting / monthly reportsConducting trials/ Follow-up / Sharing best practices meeting, follow up</td>
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<td>International Aluminium Institute</td>
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<td>Local Municipality, Environment</td>
<td>Local Government</td>
<td>Consulted</td>
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Celebrating innovation

The Process Control Potrooms and Process Control Cell Lining departments got together on Thursday 29 March 2012 to celebrate the past year’s achievements of their departmental staff in the DUBAL Suggestion Scheme and High Performance Team (“HPT”) programme. Several staff members also received certificates for successfully completing the “Lean Integrated Six Sigma Green Belt” training. Saleh Janeeh (Senior Manager: Quality Assurance & Business Excellence) and Ali H A M Al Zarouni (Vice President: Smelter Operations) presented gifts and certificates to several staff members. We also had the pleasure of having members from other departments grace the occasion, notably Sami Bustami (Senior Manager: Power Operations) and Abdulla Zarouni (Senior Manager, Technology Development & Transfer).

Maryam Mohammad Al Jallaf (Senior Manager: Process Control Potrooms & Cell Lining) and Sami Bustami (Senior Manager: Power Operations) received certificates from Saleh Janeeh and Ali H A M Al Zarouni.

Ali Jassim being recognized for his contribution to HPT 42: “Introduce track logic after anode-setting activity”. Gregory Meintjes (not pictured) was also recognized for the same project.

(From left) A Kumar and Daniel Whitfield (Departmental Managers) with Maryam Mohammad Al Jallaf (Senior Manager: Process Control Potrooms & Cell Lining) and Sami Bustami (Senior Manager: Power Operations), Ali Al Zarouni and Saleh Janeeh.

Team members recognized
Key learnings

1. Projects alignment to corporate/ BU strategy
2. Trained in the practical application of structured methodology
3. Developed better process understanding through Literature Review
4. Team work on problem solving and decision
5. Be Proactive & do benchmarking

Further Plans:
- In depth study of PFC emission during normal electrolysis process as a background emission
Project closure

Horizontal deployment:
- Rolled-over to five different electrolysis cell technologies (D18, CD20, D20, DX and DX+)
- Implementation to group companies
- Experience for future DUBAL Cell Technologies

Team recognition:
- Project team rewarded by Quality Department
- Nominated for ASQ – 2013-14 International Team Excellence Award Process
Why this project is an excellent improvement example?

- **Global** environmental impact
  - reduce CO2 eq. emissions by $\geq 95000$ tpa – based on 95 kg/t Al
  - *Sustained* and recurring emission reduction every year

- Directly contribute to **DUBAL’s long-term Environmental Performance**
  - Improves standing/rank w.r.t. to **International Benchmarks (IAI)**
  - Promote DUBAL as role model in **sustainable business** approach

- Potential savings of **1.9 million US$** if a **greenhouse tax** of 20 US$/$t is applied

- Additional benefits – e.g. improved productivity and reduced exposure of workforce to heat and pollution so on
THANK YOU